Polyetheretherketone as a Bearing Surface in a Metal Free Total Knee Arthroplasty

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Introduction: Total knee arthroplasty (TKA) utilises metal on polyethylene (MoP) bearing couples. Though reasonably successful, the long term radiological and clinical follow-up show that the early success rate is not maintained over a 10 – 15 year period when a proportion fail requiring revision surgery. Periodically, for reasons attributed to stress shielding and the possibility of metal ion generation in TKA, research interest has been directed towards all polymeric, isoeleastic joint replacement. The use of a low modulus, low wearing biomaterial may be a suitable alternative to cobalt chromium (CoCr) femoral components. Based on its favorable mechanical properties and clinical success especially in spinal surgery, we investigate polyetheretherketone (PEEK) as a candidate material for a metal free TKA. Theoretical advantages of an all polymer TKA will include, more physiological stress distribution in the distal femur, better radiographic visualisation of the bone implant interface with plain radiograph, CT or MRI and elimination of a biological reaction to metal, which may be one of the reasons for unexplained knee pain following TKA. In addition, polymers afford a cheaper option for the manufacture of prostheses.

Aims and Hypothesis: This study investigated the wear performance of PEEK and carbon reinforced PEEK (CFR-PEEK) as bearing materials in an all polymer TKA using a unidirectional pin on plate test. Our hypothesis was that reduced wear is generated from PEEK or CFR-PEEK bearings when compared with metal on polyethylene (MoP) bearings and that this combination may provide a suitable alternative in TKA.

Methods: A validated modification of ASTM F732 was used as the test protocol. Pin geometry and applied load were modified to simulate the loading and major motion conditions of the knee joint. Twenty millimeter diameter spherically ended pins with a radius of 25mm were articulated against 40mm diameter plates. A load of 1000N was applied to generate a contact stress of ~70MPa, similar to high contact stresses previously reported in non congruent knee designs. Ten material combinations were tested as shown in Table 1.

Articulations were lubricated with 25% newborn calf serum containing 0.3% sodium azide to retard bacterial growth and 20mM EDTA to prevent calcium deposition. Three repeats of pin on plate combinations (including 2 passive soak controls to correct for fluid uptake) were tested for 2 million cycles (MC) at a cycle frequency of 1Hz and a cycle length of 20 mm. Gravimetric wear was analysed every 250,000 cycles and results converted to volumetric wear using material density. Lubricant fluid was subjected to an acid digestion protocol (ISO 17853:2011), using SEM images and image analysis software to characterize the size and shape of wear particles. Non-contact surface profilometry was carried out using an interferometer (Contour GT Scanning scope, Bruker, USA) before commencement of the test and at one and two million cycles.

Results: All CFR-PEEK articulations were stopped either due to high friction, black discoloration of lubricant fluid or excessive wear of the counter-surfaces with CFR PEEK-on-UHMWPE generating 400 fold wear loss (458.52 X 10^3 mm^3/MC) compared with CoCr-on-UHMWPE (1.67 X 10^3 mm^3/MC). Linear wear rates were noted from all UHMWPE and XLPE plates over the test period. PEEK-on-XLPE showed similar wear rate to metal on polyethylene (MoP) bearings (Fig 1). Also, wear particle sizes measured as equivalent circle diameter from PEEK-on-XLPE articulations (0.17 ± 0.12µm) were similar to that observed from CoCr-on-XLPE articulations (0.19 ± 0.16µm); p=0.067.

At the end of the test, prominent rippling was observed on all plates articulated against plastic pins, while polyethylene plates articulated against CoCr pins showed polished wear track with light linear scratching. XLPE plates articulated against CoCr pins showed significant reduction in surface roughness from commencement to end of test (Ra start = 719.98 ± 49.11 nm; Ra end = 205.18 ± 37.98nm, p<0.001). Similar significant reduction in surface roughness was also noted in XLPE plates articulated against PEEK pins (Ra start = 737.91 ± 6.91 nm; Ra end = 443.76 ± 23.84 nm, p<0.05).

Discussion: Using a high contact stress value, PEEK pins articulated against XLPE plates generated volumetric wear similar to that observed in MoP bearings. Particles generated from PEEK-on-XLPE and CoCr-on-XLPE articulations were also observed to have similar size distribution and morphology. From these results, it may be possible to replace CoCr in TKA with PEEK which may be beneficial because of the low elastic modulus and elimination of biological activity to metal alloy. In this study, CFR PEEK was found unsuitable as a bearing surface for an all polymer TKA.

Significance: An all polymeric PEEK-on-XLPE bearing may be a promising alternative to MoP in total knee arthroplasty.

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<th>PEEK vs. UHMWPE</th>
<th>CFR-PEEK vs. CFR-PEEK</th>
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Table 1: Tribological couples tested (Pin vs. Plate) UHMWPE – ultrahigh molecular weight polyethylene GUR 1050, XLPE – highly cross-linked polyethylene – GUR 1020, 7.5MRad)

Fig 1: Average wear ± SD of materials tested to 2MC. Asterisk depicts significance p<0.05 (Mann Whitney U test) when compared to volumetric wear loss of CoCr vs. XLPE combination.

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